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A STUDY OF FLICKER NOISE IN MOSFETS.(U)
JUN 79 A V ZIEL DA-ARO-D-31-124-72-G121
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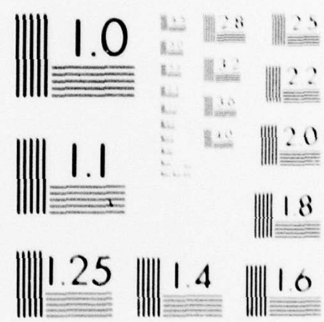

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Considerable progress was made in two areas:

1. Better understanding of flicker noise in MOSFETs.
2. Better understanding of hot electron noise in JFETs.

In addition, considerable clarification was obtained in the understanding of flicker noise problems in general. This report summarizes the research efforts in the above areas.

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I. Work Accomplished under the Contract

During the two-year period considerable progress was made in two areas:

1. Better understanding of flicker noise in MOSFETs.
2. Better understanding of hot electron noise in JFETs.

In addition, considerable clarification was obtained in the understanding of flicker noise problems in general.

1. Flicker Noise in MOSFETs

Mr. S. Y. Pai completed his Ph.D. thesis[1] and accepted industrial employment. The experimental results were that the flicker resistance in p-channel devices at low drain voltages varied as $V_g - V_T$, where V_g is the gate voltage and V_T the turn-on voltage of the channel, whereas in n-channel devices at low drain voltages R_n was nearly independent of the gate voltage over a wide voltage range. This difference is associated with the effective surface state density at the Fermi level in the two cases. Corresponding to this is a difference in behavior with respect to the drain voltage dependence of R_n.

Dr. Takagi measured the flicker noise resistance R_n in MOSFETs at relatively high frequencies as a function of temperature[2]. He obtained an interesting temperature dependence of the noise. The relationship between the voltage dependence and the temperature dependence is not yet fully clarified and more work is need on the problem.

Dr. Takagi demonstrated[3] that GaAs FETs showed a large amount of flicker noise at elevated frequencies, whereas it is well known that silicon JFETs have none to speak of. This seems to be associated with differences in structure and with differences in the surface state density.

Dr. Takagi studied noise in silicon MOSFETs made by the DMOS process[4,5]. SD-200 devices showed 1/f noise below 50 kHz and $1/f^{0.6}$ noise above 50 kHz, with a difference in voltage and current dependence in the two regimes. DE-10 devices, however, showed $1/f^{0.6}$ noise throughout. Since the DE-10 is an $n^+ - p - n^- - n^+$ device with the gate covering the $p - n^-$ regions, and the SD-200 is an $n^+ - p - p^- - n^+$ device with the gate covering the $p - p^-$ regions, this associates the 1/f noise with the p^-- region and the $1/f^{0.6}$ noise with the p- region. The n^-- region seems to show no 1/f noise, presumably because it is an accumulation layer; the p- and p^-- regions are inverted and give 1/f-type noise.

Mr. H. D. Park[6] studied 1/f noise in SOS-MOSFETs under another project, but since the results are directly related to our problem, we give here a short description. The noise behavior is quite similar to that of normal silicon MOSFETs, but the noise was about one order of magnitude larger, presumably because of the larger density of oxide traps near the interface.

Mr. Pai[1] and Mr. Park[6] investigated methods for measuring surface state densities and used their results in the interpretation of their noise data.

Mr. Park has measured the surface mobility μ in silicon MOSFETs and found a large dependence of μ on gate voltage. This effect will greatly complicate the interpretation of flicker noise in MOSFETs at arbitrary drain voltage.

Van der Ziel[7] derived some general relationship for noise in MOSFETs under the assumption that μ was independent of $V_g - V_T$. These calculations should be repeated by incorporating the dependence of μ on $V_g - V_T$ (see ref. [9]).

Jindal[8] has shown that the noise in MOSFETs should decrease at low inversion. If δN is the fluctuation in the number of free carriers and δN_t the fluctuation in the number of trapped carriers in the oxide near the interface, then the noise must be multiplied by R^2, where $R = -\delta N/\delta N_t$. A calculation showed R to be unity at strong inversion , but very much smaller than unity at weak inversion.

Van der Ziel[9] has developed a unified theory of flicker noise in MOSFETs which is a blend of earlier theories. The noise is found to be proportional to a properly defined "effective surface state density". Incorporation of mobility fluctuations into the theory yields that the noise must be multiplied by the factor

$$\left(-R + \frac{N}{\mu}\frac{d\mu}{dN_t}\right)^2$$

where N is the number of free carriers, N_t the number of trapped carriers and μ the mobility; for weak inversion the second term, which is due to mobility fluctuations, can predominate. An attempt was also made to incorporate the dependence of μ on $V_g - V_T$ in the evaluation of R_n at arbitrary drain bias.

Takagi[10] measured drain noise in MOSFETs at zero drain bias as a function of the gate voltage and the temperature. The noise was white, as expected, but was somewhat larger than the thermal noise of the drain conductance g_o. Apparently a MOSFET at zero

bias is not quite in an equilibrium situation, presumably because a large transverse field is acting on the channel. This requires further study.

2. Hot Electron Noise in JFETs and MOSFETs

Mr. S. K. Kim[11] measured the parameter $\alpha = R_n g_m$ in silicon JFETs at saturation. Here R_n is the noise resistance and g_m the transconductance at saturation. For long-channel devices this parameter has a value of about 2/3 but for the short-channel devices investigated here α was somewhat larger, presumably because of hot electron effects. At a given absolute temperature T the parameter α increased with increasing value of $V_g - V_p$, where V_p is the pinch-off voltage; at a given V_g the parameter α increased with decreasing T, such that $T\alpha(T)$ was approximately a constant. Extrapolation to 77°K would yield a value of $\alpha(T)$ of about 4-5.

Measurements near 77°K indicated[12], however, that the noise resistance R_n at 77°K was more than one order of magnitude larger than the above extrapolation would give, and was strongly temperature dependent; R_n had an activation energy of 0.062 eV. Since it was not expected that hot electron noise would show such an activation energy, it was concluded that this noise was generation-recombination noise of donors in the channel. In such a case, however, one would expect an activation energy of 2 E_o, or about 0.088 eV, where E_o is the activation energy of the donors (see below).

Nougier et al.[3] had interpreted the noise in silicon bars and JFETs at 77°K as hot electron noise. Van der Ziel et al.[14], however, were able to interpret their data as generation-recombination

noise. By taking into account the effect of the electric field on the activation energy of the donors (Poole-Frenkel effect) they could obtain excellent agreement between theory and experiment. They also extended the low-field generation-recombination noise theory to the hot electron regime and were able to account for the activation energy of 0.062 eV as a manifestation of the Poole-Frenkel effect.

Takagi[3] measured hot electron noise in GaAs FETs as a function of bias and temperature and found that it increased with decreasing temperature T, but to a much lesser extent than in Si JFETs. There was apparently no activation energy of the noise, which makes it likely that the observed noise is true hot electron noise.

Takagi[2] also measured hot electron noise in silicon MOSFETs as a function of bias and tamperature. He found indeed an increase in noise at lower temperatures, but there was apparently no activation energy involved. Since the noise parameter α was much larger than unity near room temperature in this case, it is somewhat doubtful whether the observed noise was true hot electron noise. This requires further study.

3. General Flicker Noise Problems

One of the outstanding issues in flicker noise theory is whether it is due to a surface effect or a bulk effect, and whether number fluctuations or mobility fluctuations predominate. We obtained some clarification in these areas.

One of the first indications that flicker noise might be due to mobility fluctuations was found in flicker noise in electrolytic

concentration cells[14]. Fully correlated bulk fluctuations in the density of positive and negative ions could not explain the data whereas mobility fluctuations could explain the data under one assumption. Van der Ziel[15] was able to show, however, that a surface effect would lead to partially correlated positive and negative ion number fluctuations, and this could explain the data at least as well.

Another indication came from the fact that the noise intensity of semiconductor resistors decreased considerably by going to higher doping levels[16]. The results could be interpreted in terms of mobility fluctuations by assuming that only lattice scattering was noisy. Van der Ziel[17] was able to show, however, that the data could also be interpreted by number fluctuations.

Probably the strongest argument against a bulk effect comes from the absence of flicker noise in silicon JFETs. Assuming the noise to be a bulk effect, having the same order of magnitude as in other semiconductor devices, van der Ziel[18] calculated $R_n \simeq 10^{10}/f$ ohms. In fact, R_n is at least 5 orders of magnitude smaller than this and is of the generation-recombination noise type. Therefore, any bulk effect is ruled out here. And if it is ruled out for JFETs, it must be ruled out for other devices also.

The difference between silicon JFETs and most other semiconductor devices is that the former have no accessible semiconductor-oxide interface. This points to the interface as the source of the noise[18].

There are now two effects to be considered[18]:

1) The fluctuation occupancy of the oxide traps gives rise to fluctuations in the number of carriers. This leads to the number fluctuation model.

2) The fluctuating occupancy of the oxide traps causes fluctuations in the surface potential, which, in turn, gives rise to mobility fluctuations. This gives the mobility fluctuation noise a physical basis.

Van der Ziel[9] has combined these two effects in an interpretation of flicker noise in MOSFETs.

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II. Degrees Granted during the Period

1. M.Sc. Degree, R. P. Jindal

   Plan B Paper: "Carrier fluctuation noise in a MOSFET channel due to traps in the oxide".

2. M.Sc. Degree, S. K. Kim, March 1979

   Plan B Paper: "Hot electron noise and generation-recombination noise in silicon bars and JFETs.

3. S. Y. Pai, Ph.D. Degree, August 1978.

   Theory and experiments of low-frequency 1/f noise in MOSFETs.

III. Publications Published during the Period

See list of publications, except numbers 1, 6, 13, 16.

In addition

19. A. van der Ziel, Theoretical review of 1/f noise, (invited paper), Proceedings of the Symposium on 1/f Fluctuations, The Sasakawa Hall, Tokyo, Japan, July 11-13, 1977 Conference Report, pp. 1-6.

20. W. Baril, H. M. Choe, A. van der Ziel and S. T. Hsu, High-frequency thermal noise in MOSFETs, Solid State Electronics, 21, 589, 1978.

IV. Personnel Employed on Contract

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S. K. Kim	3/16/77 - 4/1/79	
S. Y. Pai	3/16/77 - 8/31/78	
R. P. Jindal	8/16/78 - 9/16/78	
H. Park	9/16/78 - 4/1/79	
K. Takagi	8/1/77 - 7/31/78	Without Charge